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Towards Focus on Time

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Abstract: On specifying and verifying timing system properties in a formal way.

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Specifying real-time systems, arguing about timing properties is hardly avoidable. The notion of time takes center stage for this kind of systems: abstracting from the time we may lose the core properties of a system we represent, e.g. in many cases the causality property can be lost. In particular, the timed domain is the most important one for representation of distributed systems with real-time requirements.

On the other hand, in many cases arguing about time makes the specification more readable for an average engineer: specification of a real-time system in an untimed frame may be in some cases shorter or more elegant from mathematical point of view, but to understand such specifications and to argue about their properties is in many cases much more difficult in comparison to the corresponding specifications in a timed frame, where some properties like causality could be represented explicitly. Moreover, abstraction from timing aspects can easily lead to specification mistakes because of difficulties to find a correct abstraction.

One of the most well-established models for the specification and verification of real-time system design is representation of a system using timed automata, introduced by Alur and Dill [AD94] – they extend the classical finite automata by a finite set of real valued clocks used to measure the time elapsed between events to constrain the runs of the automaton. The model from Alur and Dill is well-developed, however, some its assumptions on the system could be too idealistic: timed automata assumes perfect continuity of clocks and, what could be even more critical if we deal with embedded systems, instantaneous reaction times. Another problem of this model is that it does not prevent Zeno runs [GB07]. To solve this, the idea of robust model checking was introduced by Puri [Pur00] and also revised in other approaches.

We suggest another solution: to argue not about a single action or messages but about time intervals containing a finite number of actions, i.e. to argue not about single messages in an input stream, but about a sequence of messages that are present in this stream at some time interval. This sequence can be in general either empty or contain a single message or a number of messages. In this approach a discrete model of time is used, because (i) this simplifies the specification and, even more, the verification of system properties, and (ii) any timed transition system can be discretized without loss of generality. Thus, an input for our timed automata or, more generally, a timed component, is an infinite sequence of finite time intervals.

However a discrete model of time is used here, ones can choose any time granularity defining the concrete meaning of a time interval according to the system requirements, and, moreover, it is possible to switch from one time granularity to another: the operator $s \downarrow_n$ refines the time granularity splitting every time interval of the stream s into n time intervals (there is a number of

strategies to apply for the split action), where the operator $s \vee_n$ makes the time granularity more coarse – it joins n time intervals of the stream s into a single time interval. We can use any granularity defining the concrete meaning of a time interval according to the system requirements, but one of the main problems with the timed automata – Zeno runs – still be excluded.

To make specification more readable and to simplify the verification of the corresponding system properties, we introduced, in addition to the representation as state machines (timed automata), also a special kind of tables and a number of other operators for the formal specification of real-time systems (as well as auxiliary lemmata over them): from untimed causal simulation and timed merge to the operators for the analyzing of crypto-based distributed software and their composition. To avoid misinterpretations, we call our kind of timed automata by *timed state transition diagrams* (TSTDs). Specifying system behavior by TSTD we can use three specification styles: diagram, table and a textual style.

The TSTD-approach can be applied within any specification/verification language, nevertheless we prefer to present it using FOCUS [BS01], a framework for formal specification and development of interactive systems, to take advantage of its features, inter alia the well-developed theory of composition and extensions based on human factor analysis within formal methods [Spi12]. Using this approach, one can verify properties of a system in a formal way according to the methodology “FOCUS on Isabelle”[Spi07], by translating the FOCUS specifications to the semiautomatic theorem prover Isabelle/HOL [NPW02], an interactive semi-automatic theorem prover, and using the Isabelle tool to make the proofs.

The feasibility of the proposed approach has been demonstrated by two industrial case studies from automotive area, motivated by DENSO Corporation and Robert Bosch GmbH.

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